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Taming the Bullwhip Effect in Complex Business Environments

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Abstract:

Our PLS analysis of GMRG data from 91 small machine tool manufacturers showed that Business Complexity, comprised of product diversity and supply chain uncertainty, caused firms to use demand forecasting and inventory management systems more, and this use decreased inventory efficiency.

Introduction:

The fundamental questions of whether and how information technology (IT) contributes to firm performance have been answered in different ways. Thus, research findings have been equivocal, some studies finding negative performance impacts, some finding no overall effect, some finding positive impacts. To reconcile these findings, several studies suggest that contextual factors associated with the firm and/ or its environment moderate IT's performance effects (c.f., Banker, Kauffman and Morey, 1990; Brynjolfsson and Yang, 1997; Weill, 1992).

A key theme emerging from supply chain management literature is the substitution of IT for physical inventory. When inventory is managed effectively, when forecasts more accurately predict future demand, uncertainty is decreased, and inventory buffers are reduced, as "just-in-case" inventories become "just-in-time".

"Inventory and work-in-process are purely physical things, but if information were accurate and timely, factories could operate with a fraction of their current inventory. Inventory is merely the physical correlate of deficient information"
(Evans and Wurster, 2000:10).

Performance implications are substantial, as reduced holding costs and greater number of inventory turns result in working capital efficiencies and improved cash flows. For instance, streamlining the inventory inefficiencies in the grocery supply chain could save an estimated \$30 billion (Lee, Padmanabhan and Whang, 1997).

Significant efficiencies can thus be realized as the "Bullwhip Effect" is tamed. The "Bullwhip Effect" refers to the phenomenon in which demand forecasts' variances are considerably amplified, the further up the supply chain the forecasts are made (Bhaskaran, 1998; Lee, Padmanabhan and Whang, 1997; Towill, 1991; Houlihan, 1987; Stermann, 1987). It tends to increase with longer

lead times, order batching, price fluctuation, Kanban use and rationing gaming.

This study empirically tests some of these ideas, using data specific to the small machine tool manufacturing industry, from the Global Manufacturing Research Group (GRMG) survey. Our research question asks, "How does IT-enabled manufacturing planning and control (MPC) capability mediate the relationship between business complexity and inventory productivity?" The next section discusses relevant research and our hypotheses. The third section introduces the proposed model and constituent definitions. The fourth section outlines the design of our empirical study. The last section discusses the results and their implications for management practice and future research.

2.0 Theoretical Basis of Research:

IT value research has given equivocal results, perhaps because measures and models used to study complex business and market systems have been too simplistic. We're suggesting that many factors interact with IT to influence a firm's performance, and the outcome depends on measurements used. Our choice to consider the IT - Business Complexity interaction, and its effect on inventory productivity is motivated by literature summarized in the next sections.

2.11 Main effects:

Business Complexity on Performance:

Business Complexity is defined as "...the scale and difficulty of buying and selling processes" (Holland and Lockett, 1997). A less complex firm combines a minimal number of parts from a minimal number of reliable suppliers into a minimal number of relatively homogeneous products in a predictable market, with short plan horizons, and infrequent revisions.

Products with unpredictable demand are categorized as innovative, requiring a shift in manufacturing focus from efficient capacity utilization to effective deployment of buffers (Fisher, 1997). Business Complexity should therefore decrease inventory productivity, as the firm attempts to buffer itself from uncertainty using inventory, and as more product lines and more part numbers inflate inventory levels.

Firms thus react to higher schedule instability (forecasting error, and supply chain unreliability) with inventory buffers. Longer planning periods and more frequent plan revisions also signal market uncertainty, which can be buffered with inventory.

"Inventory and work-in-process are purely physical things, but if information were accurate and timely, factories could operate with a fraction of their current inventory. Inventory is merely the physical correlate of deficient information" (Evans and Wurster, 2000:10).

The economic impact of better coordinating supply chains is huge, regardless what industry one considers. For instance:

"Various industry studies found that the total supply chain, from when products leave the manufacturers' production lines to when they arrive on the retailers' shelves, has more than 100 days of inventory supply. Distorted information has led every entity in the supply chain--the plant warehouse, a manufacturer's shuttle warehouse, a manufacturer's market warehouse, a distributor's central warehouse, the distributor's regional warehouse, and the retail store's storage space--to stockpile because of the high degree of demand uncertainties and variabilities. It's no wonder that the [Efficient Consumer Response] ECR reports estimated a potential \$30 billion opportunity from streamlining the inefficiencies of the grocery supply chain" (Lee, Padmanabhan and Whang, 1997:93-94).

In addition to decreasing coordination complexity, maintaining fewer suppliers per part enables closer relationships, which encourages richer supply chain communication and more effective information management. In essence, a transaction-based focus to suppliers is inadequate in complex business environments.

IT on Performance:

"Productivity Paradox" is a term coined to describe the decline in productivity growth that began in the 1970s, just as information technology (IT) investment began to dramatically increase. Labor productivity growth slowed from 2.5% per year from 1953 to 1968, to 0.7% per year from 1973 to 1979. Multifactor productivity growth also fell from 1.75% a year to 0.32% over this time frame. Concurrent with these declines, office computers and machines capital rose from 0.5% of all producers' durable equipment in the 1960s to 12% in 1993 (Brynjolfsson and Yang, 1996).

Berndt and Morrison (1995) reported a negative correlation between total factor productivity and high-tech capital formation during 1968-1986. Loveman (1994) found a gross margin close to zero for 60 manufacturers

over a five-year period. Though Barua, Kriebel and Mukhopadhyay (1995) found a positive relationship between IT and three intermediate variables, it was too small to affect final output in their manufacturing sample. Weill (1992), after disaggregating IT by type of use, found productivity to be positively associated with transactional IT use, but negatively associated with strategic IT use, and no productivity associations with informational IT uses.

On the other hand, Brynjolfsson (1993), and Hitt and Brynjolfsson (1996) found that IT produced gross margin increases of 60% on a macroeconomic level, but no profitability increase. Brynjolfsson and Yang (1997) found that a one-dollar increase in the quantity of installed computer capital is associated with a ten dollar-increase in firm valuation by financial markets (four times more than actual computer capital on the open market).

2.12 Interaction effects:

IT with Business Complexity on Performance:

Holland (1995) suggested that IOS have shifted the focus of strategic analysis from the level of the individual firm to that of the total supply chain. Firm competitiveness depends on efficiencies and effectiveness only possible through supply chain cooperation and coordination. Bhaskaran suggests that,

"Stable production schedules are important when managing supply chains as they help control inventory fluctuation and inventory accumulation. Failure to control schedule instability results in high average inventory levels in the system" (1998:633).

To the extent that MPC systems enable this cooperation and coordination, they should mediate business complexity's impact on inventory productivity. Holland and Lockett (1997) propose a research framework in which interorganizational systems (of which MPC is an example) interact with the effects of business complexity, and suggest that future research should consider implications for performance outcomes.

Ghemawat & Costa cast information architecture decisions in terms of the static-dynamic dichotomy, saying, "A key concern in defining decision rights is the trade-off between the information or knowledge problem and the control problem" (1993:63). Extensive information capabilities can more effectively access idiosyncratic knowledge across the organization and supply chain, and thereby enhance responsiveness. This knowledge access and responsiveness should differentially enhance performance in unstable, uncertain environments. Broadbent, et.al. link IT capability with business complexity, saying, *"Greater IT infrastructure capability is required where firms need to respond more rapidly to changes in the market place"* (1997:175).

Rai and Bajwa (1998) present empirical evidence indicating that firms operating in complex environments were more likely to adopt EIS for decision support. If

these firms are assumed profit maximizing, market complexity and IT can be construed as interacting to positively influence performance. This inference would mesh well with Banker, Kauffman and Morey's (1990) empirical finding that the use of point of sale and order management IT in Hardee's restaurants enabled higher efficiency in those stores having more complex menus.

Alternatively, Fisher (1997) suggests that companies selling diverse, high contribution margin products in uncertain markets should manage processes to maximize responsiveness, rather than efficiency. He suggests that these functions are mutually exclusive, in that the former maximizes revenue using more WIP and finished goods inventory. The latter minimizes production and inventory cost. Thus, he suggests MPC systems requiring long, frozen production schedules are not suitable for unstable, high complexity contexts.

2.2 Research Hypotheses:

In summary, we hypothesize:

H1) Business Complexity will be negatively associated with Performance, as measured by Inventory Productivity.

H2) Business Complexity will be positively associated with MPC Capability.

H3) An extensive MPC capability in a more complex business will be associated with better Performance, as measured by Inventory Productivity.

3.1 Research Model:

Schematically, these hypotheses are represented with the IT Value model in Figure 1.

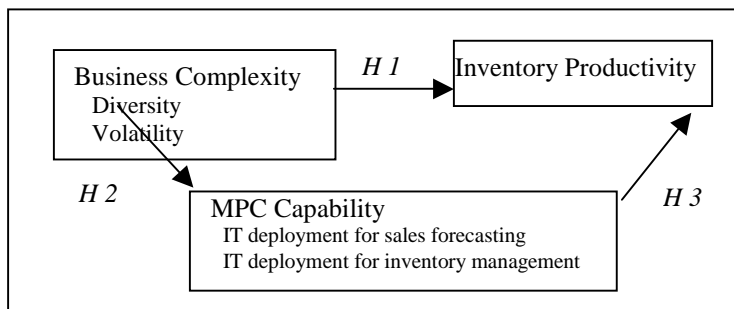


Figure 1. IT Value Model.

3.2 Variable Definitions:

MPC Capability is defined as the enabling base of shared IT capabilities which "...provides information to efficiently manage the flow of materials,...coordinate internal activities with those of suppliers, and communicate with customers about market requirements" (Vollmann, Berry, and Whybark, 1992:2). This technology illustrates what Rockart

and Short say is IT's most important role: to enable firms to manage organizational interdependence (1989). Management of interorganizational interdependence is enabled as well, to the extent that MPC systems span organizational boundaries, and can thus be considered interorganizational systems (IOS). These definitions and subproperties are summarized in Table 1 below.

<p>MPC Capability: the enabling base of shared IT capabilities which provides information to efficiently manage the flow of materials,...coordinate internal activities with those of suppliers, and communicate with customers about market requirements". (Limited \leftrightarrow Extensive)</p> <p>A. COMPUSE1: Extent of IT Deployment for sales forecasting (Limited \leftrightarrow Extensive)</p> <p>B. COMPUSE4: Extent of IT Deployment for inventory management (Limited \leftrightarrow Extensive)</p>
--

Table 1. MPC Capability

Business Complexity is defined as "...the scale and difficulty of buying and selling processes" (Holland and Lockett, 1997). A less complex firm combines a minimal number of parts from a minimal number of reliable suppliers into a minimal number of relatively homogeneous products in a predictable market, with long lead times and plan horizons, and frequent revisions.

Thus, Business Complexity is comprised by two dimensions: diversity and volatility. Diversity is measured by the firm's number of parts in its raw materials and finished goods inventories, its number of suppliers/part, and number of product lines produced. Volatility refers to the degree of unpredictability in production scheduling. It is measured by suppliers' delivery unreliability; % forecasting error, frequency of late changes in delivery due dates; frequency of late engineering and design changes; production plan length and its frequency of revision. Business complexity's constituent dimensions and scales are summarized in Table2.

Business Complexity--the scale & difficulty of buying and selling processes in the marketplace.
(Less \leftrightarrow More)

A) **Diversity:** Scale of the firm's processes.
(Less \leftrightarrow More)

1. RAWNUM: Number of part numbers in raw materials inventory: (Few \leftrightarrow Many)
2. FINNUM: Number of part numbers in finished goods inventory: (Few \leftrightarrow Many)
3. LINES: Number of product lines or product families produced: (Few \leftrightarrow Many)
4. NUM: Number of suppliers per part.
(Few \leftrightarrow Many)

Table 2. Business Complexity

Business Complexity--continued

B) Volatility: Uncertainty associated with the firm's processes. (Less \leftrightarrow More)

1. CHGPR10: How often a change in delivery due date changes the company's production schedule priorities after the plant has started an order. (Never \leftrightarrow Very Often)
2. NOTONT: Suppliers' lack of delivery reliability. (Low \leftrightarrow High)
3. ERR: Rate of forecasting error. (Low \leftrightarrow High)
4. ECH: % orders for which engineering or design changes occur after the start of production. (Low \leftrightarrow High)
5. LGTHP: How many months into future company's production plan extends. (Few \leftrightarrow Many)
6. REV: How many times per year company's production plan is revised. (Few \leftrightarrow Many)

Table 2. Business Complexity

Inventory Productivity (INVYPR) is the dependent variable. Brynjolfsson & Yang (1996) calculate productivity as output level divided by the level of factor input. They define output as the number of units produced, multiplied by their inflation-adjusted price. Annual sales revenue will be used here as output. The use of data collected in a relatively short, low-inflationary market (i.e., 1994-1996, United States) limits inflationary effects. Thus, inventory productivity will be calculated as annual sales revenue/ inventory investment.

4.0 Empirical Study:

The (GMRG) data set contains general data, as opposed to that collected for a single research project. It includes responses from thousands of national and international respondents addressing the MPC practices of two specific industries--small machine tool manufacturing and textiles manufacturing -- and a catch all category listed as "Other". This "Other" category provided a sufficiently large sample of respondents. However, since maximum control of extraneous variables was sought, and the textile industry did not provide a sufficiently large sample (N=27), the study was limited to the small machine tool manufacturing respondents. This sample originally included 96 responses, from which five outliers were excluded, leaving a total sample size of 91.

Similarly, focus on a single IT, MPC systems (specifically, computer use for demand forecasting and

for inventory control), minimized problems associated with aggregating over all IT applications. Hopefully, this focus eliminates a situation in which "...the impacts of effective systems are neutralized by ineffective systems" (Mukhopadhyay, et al, 1995:149).

Various sampling frames and collection methods were used. Generally, in the U. S., manufacturers listed in business directories were selected by SIC code, then mailed a survey with cover letter, some preceded by a phone call (Whybark and Vastag, 1993). Approximately 250 responses were received from about 1570 U.S. surveys sent, for all three industry categories, yielding approximately 16% response rate. Individual researchers' reported aggregate response rates ranged from 4.6% to 39% (Personal correspondence from G. Vastag).

A causal model, in which Business Complexity and MPC Capability are treated as formative factors, was developed and tested, using Partial Least Squares (PLSGraph).

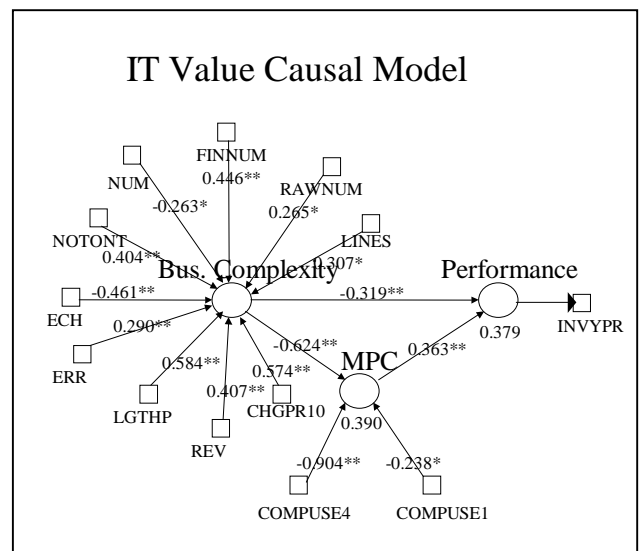


Figure 2 IT Value Causal Model

5.0 Results

The model explained 39% of the variance for MPC Capability, and 38% of the variance in Performance, as measured by Inventory Productivity. All items' weights are significant at the .05 level or better, and all path coefficients are significant at the .01 level or better.

The path coefficient relating Business Complexity with Inventory Productivity was negative, supporting Hypothesis 1. Thus, as expected, firms having greater business complexity show lower inventory productivity.

The path coefficient relating Business Complexity with MPC Capability was negative, but since both items measuring MPC Capability had negative weights, a positive association is indicated. This confirms Hypothesis 2, that Business Complexity is positively related to MPC deployment. Firms producing and selling

diverse products in volatile markets deploy more IT to support demand forecasting and inventory management.

Although the path coefficient associating MPC Capability with Performance is positive, the two items measuring MPC Capability have negative weights. This indicates a negative relationship between these items and Performance, as measured by Inventory Productivity. Thus, Hypothesis 3 was disconfirmed. This means that increased business complexity causes increased computer deployment for demand forecasting and inventory management, and this increased computer use actually decreases inventory productivity. MPC deployment thus exacerbates the negative impacts of business complexity on inventory productivity.

This result would tend to support Fisher's (1997) contention that since MRP systems require stable, frozen schedules, they do not optimize performance in volatile contexts. Prescriptive advice is difficult to draw from these conclusions, however, as this study does not analyze MPC's impact on firm responsiveness. It only measures inventory productivity, which Fisher (1997) suggests is irrelevant in contexts involving high levels of Business Complexity. If MPC systems enhance firm responsiveness at the same time they decrease inventory productivity, they may still represent good management practice. Without testing MPC systems' impact on multiple dimensions of performance, in varying degrees of business complexity, concurrently with strategic choices, normative advice would be prematurely drawn.

These results thus set the stage for further research that has important managerial implications. This study included only two MPC applications in the operationalization of MPC Capability, as the available others (computer use for production planning, for production scheduling, for purchasing and for product design) did not load significantly at the .05 level. These other items may become significant if the dependant variable, Performance, is measured more generally, using more dimensions that include both efficiency and responsiveness measures. Some such items available in the data set include the firm's relative strategic competence regarding: unit manufacturing costs, manufacturing throughput speed, product quality, delivery speed, delivery reliability, product and volume flexibility, and product design time. The impact of strategic choices and adjustments to these various business contexts also needs to be included. This stream can also be extended to other industries and to other markets, as data are available for them as well.

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